HEO and SMD Joint Activities

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Director, Planetary Science

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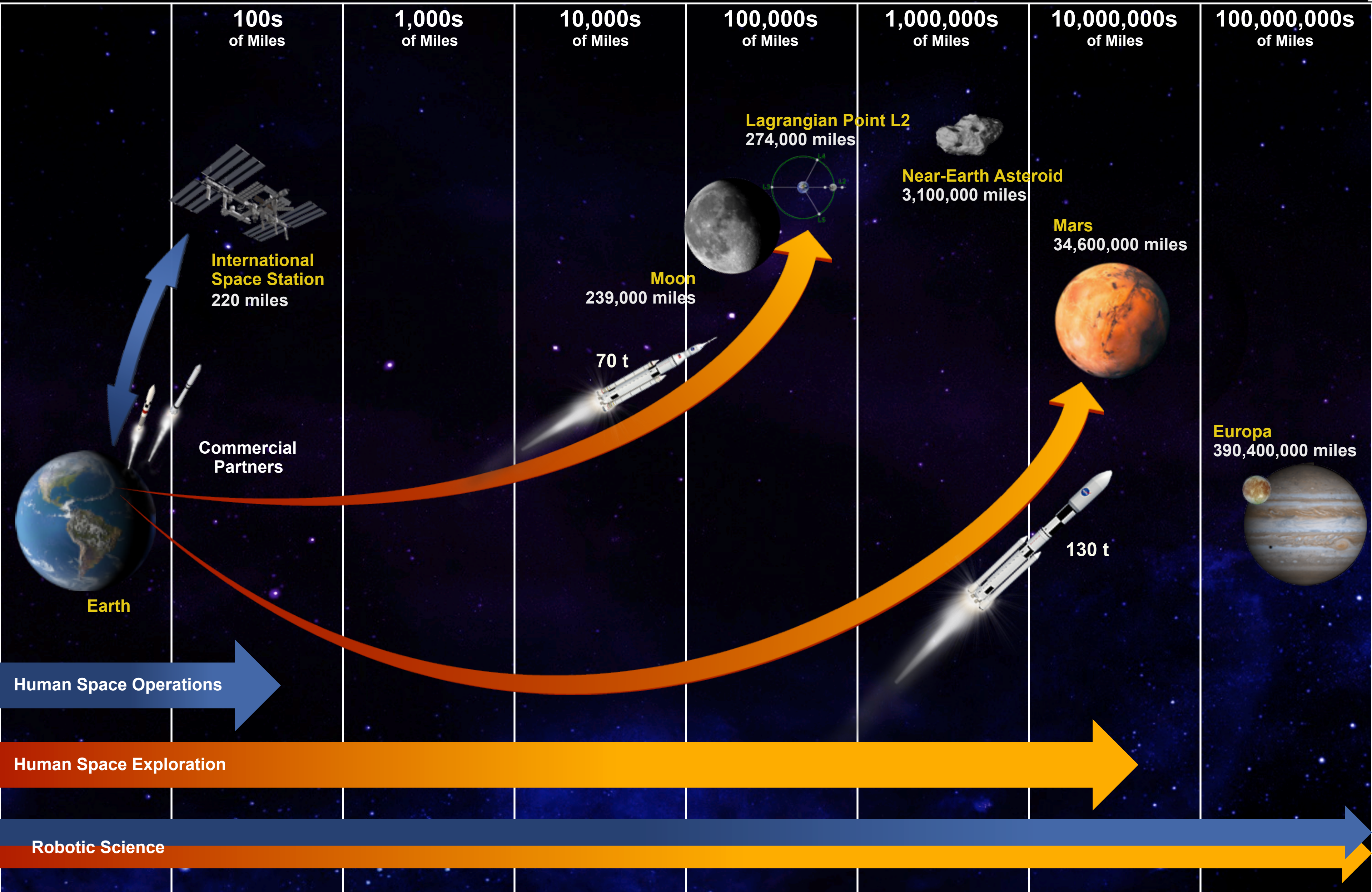
Summary: Joint Science & Exploration

- Lunar Mission: Lunar Reconnaissance Orbiter
  - LRO transitioned from ESMD to PSD as a exploration & science mission
  - Tested Laser Communications from the Moon on the LADEE mission
- Asteroid Activities:
  - Asteroid Redirect Mission
  - NEO detection and characterization
  - Planetary Radar at Arecibo and Goldstone
- Mars mission instruments:
  - Odyssey: Mars Radiation Environment Experiment (MARIE)
  - MSL: Radiation Assessment Detector (RAD), Mars Entry Decent and Landing Instrument (MEDLI)
  - Mars2020: MEDLI, ISRU
  - Strategic Knowledge Gaps (SKG)
- Research & Analysis joint activities:
  - NASA Lunar Science Institute
  - Solar System Exploration Research Virtual Institute
  - Lunar Advance Science & Exploration Research – LASER
  - Moon-Mars analog mission activities – MMAMA
- Collaborative studies and workshops
- Join AG charters (LEAG, SBAG, MEPAG)

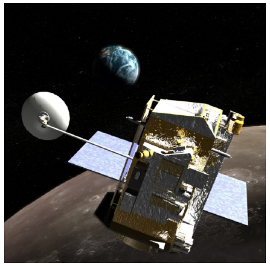
Exploration Destinations



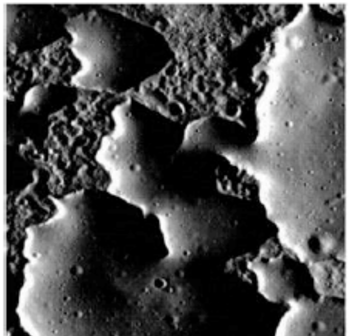
Lunar Reconnaissance Orbiter Objectives

Apollo 15 - Commander Dave Scott returns from the Rover with camera in hand. From left to right is Hadley Rille, Mount Hadley, the Swann Hills, Silver Spur, Mount Hadley Delta and St George Crater

- Safe Landing Sites
  - High resolution imagery
  - Global geodetic grid
    - Topography
    - Rock abundances
- New Technology
  - Advanced Radar
- Locate potential resources
  - Water at the lunar poles?
  - Continuous source of solar energy
  - Mineralogy
- Space Environment
  - Energetic particles
  - Neutrons

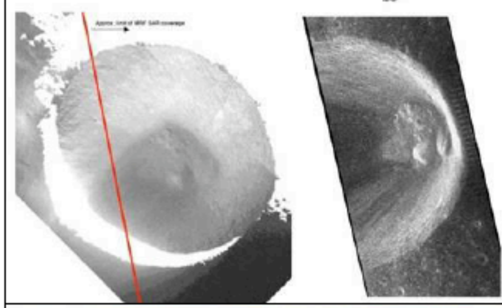


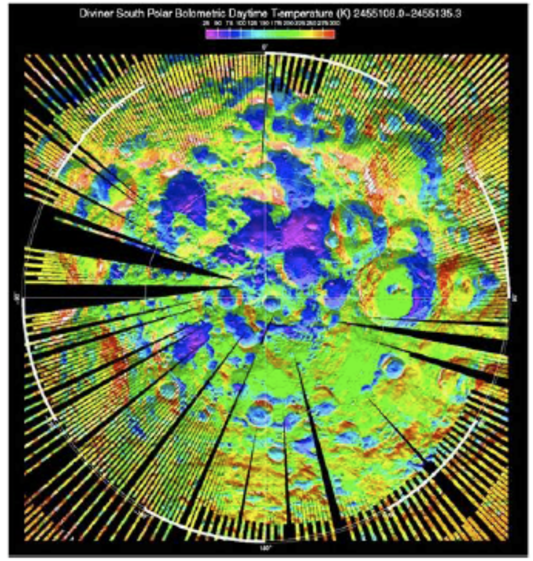
Lunar Reconnaissance Orbiter



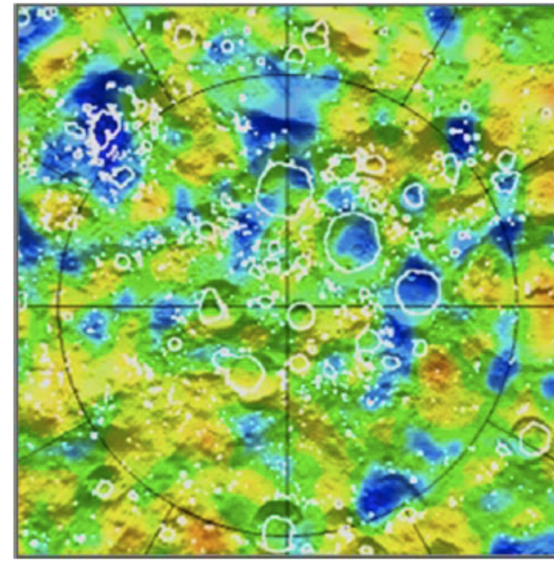
LROC (Ina)

Mini-RF – Shackleton

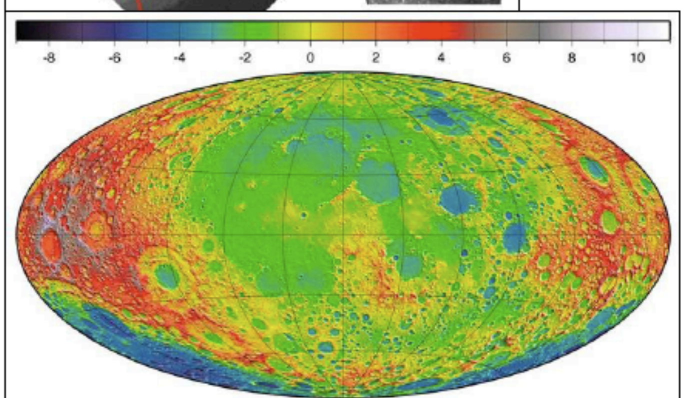




DLRE – South Pole Temp.

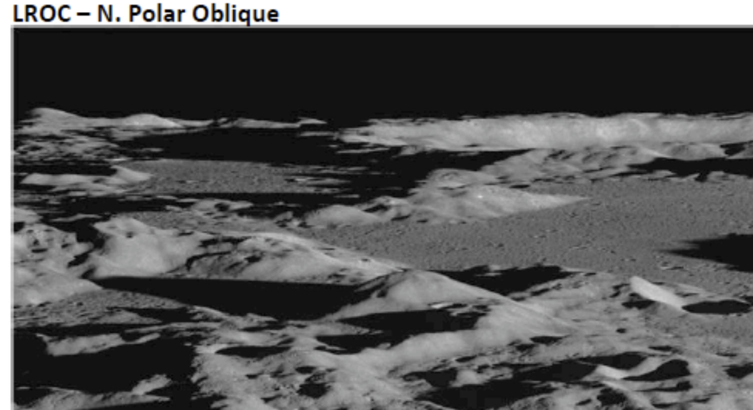


LEND – South Pole suppressed neutrons

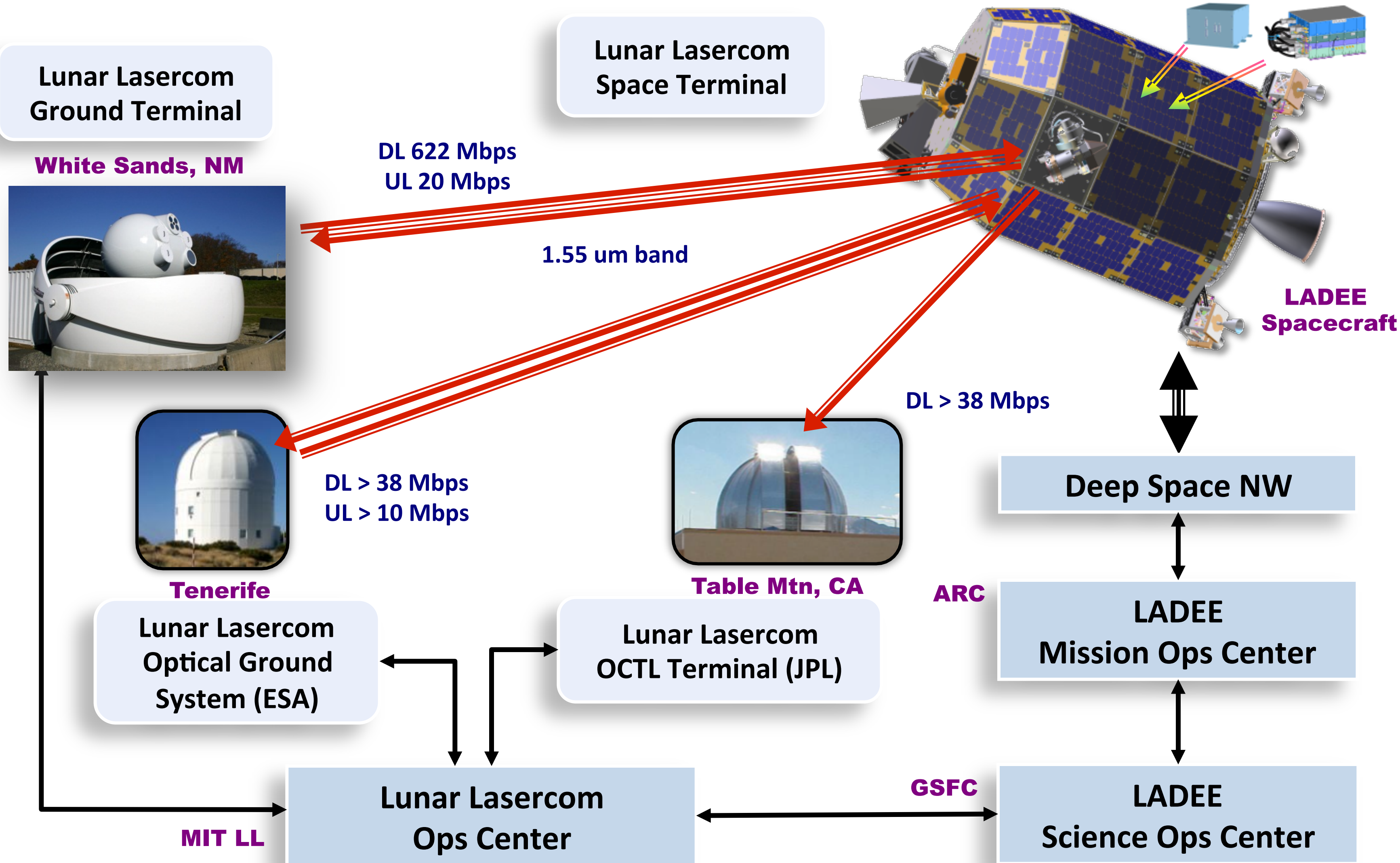


LOLA DEM

LROC – N. Polar Oblique



Lunar Laser Communication Demonstration

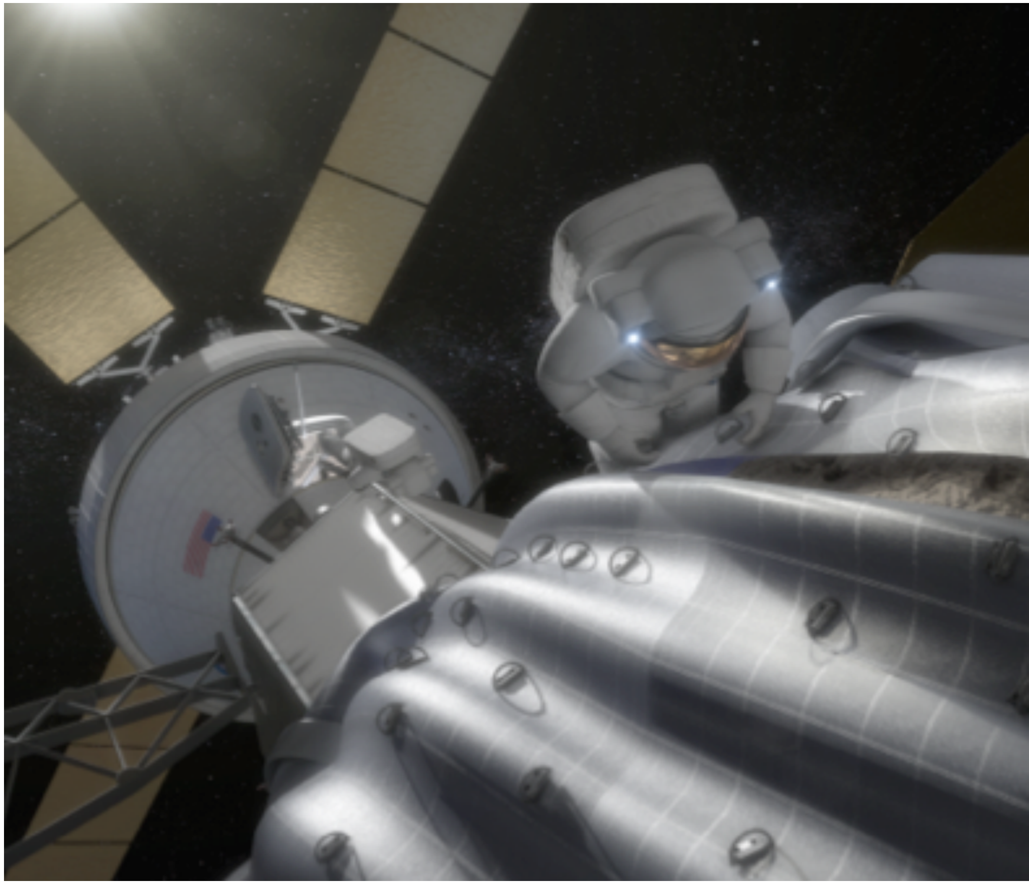


Asteroid Activities

Asteroid Redirect Mission

Builds on Investments Already Being Made by NASA

- ARM integrates several building blocks of human space exploration to initiate deep space exploration
  - ISS experience
  - Orion and SLS
  - SEP and other technologies
- Contributes significantly to the extension of the human exploration of space beyond LEO in an affordable and sustainable way
  - Operate 1000 times further than LEO for the first time in 4 decades.



Asteroid Redirect Mission: 3 Segments

Identify

Asteroid Identification:

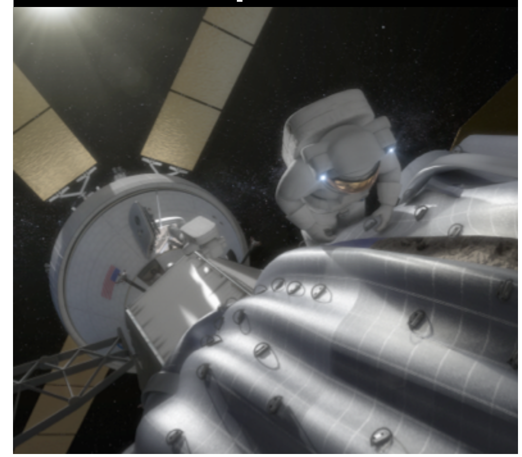
Ground and space based near Earth asteroid (NEA) target detection, characterization and selection

Redirect

Asteroid Redirect Robotic Mission:

High power solar electric propulsion (SEP) based robotic asteroid redirect to lunar distant retrograde orbit

Explore



Asteroid Redirect Crewed Mission:

Orion and Space Launch System based crewed rendezvous and sampling mission to the relocated asteroid

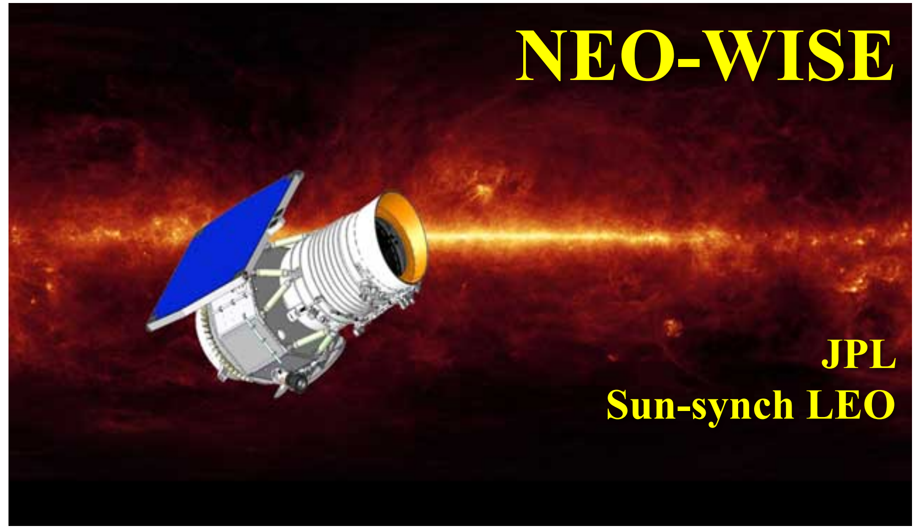
NASA’s NEO Search Program

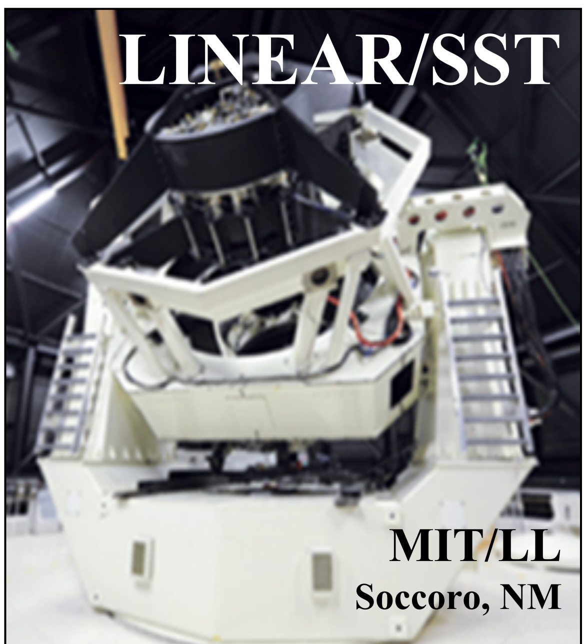
Minor Planet Center (MPC)
- IAU sanctioned
- Int’l observation database
- Initial orbit determination

http://minorplanetcenter.net/

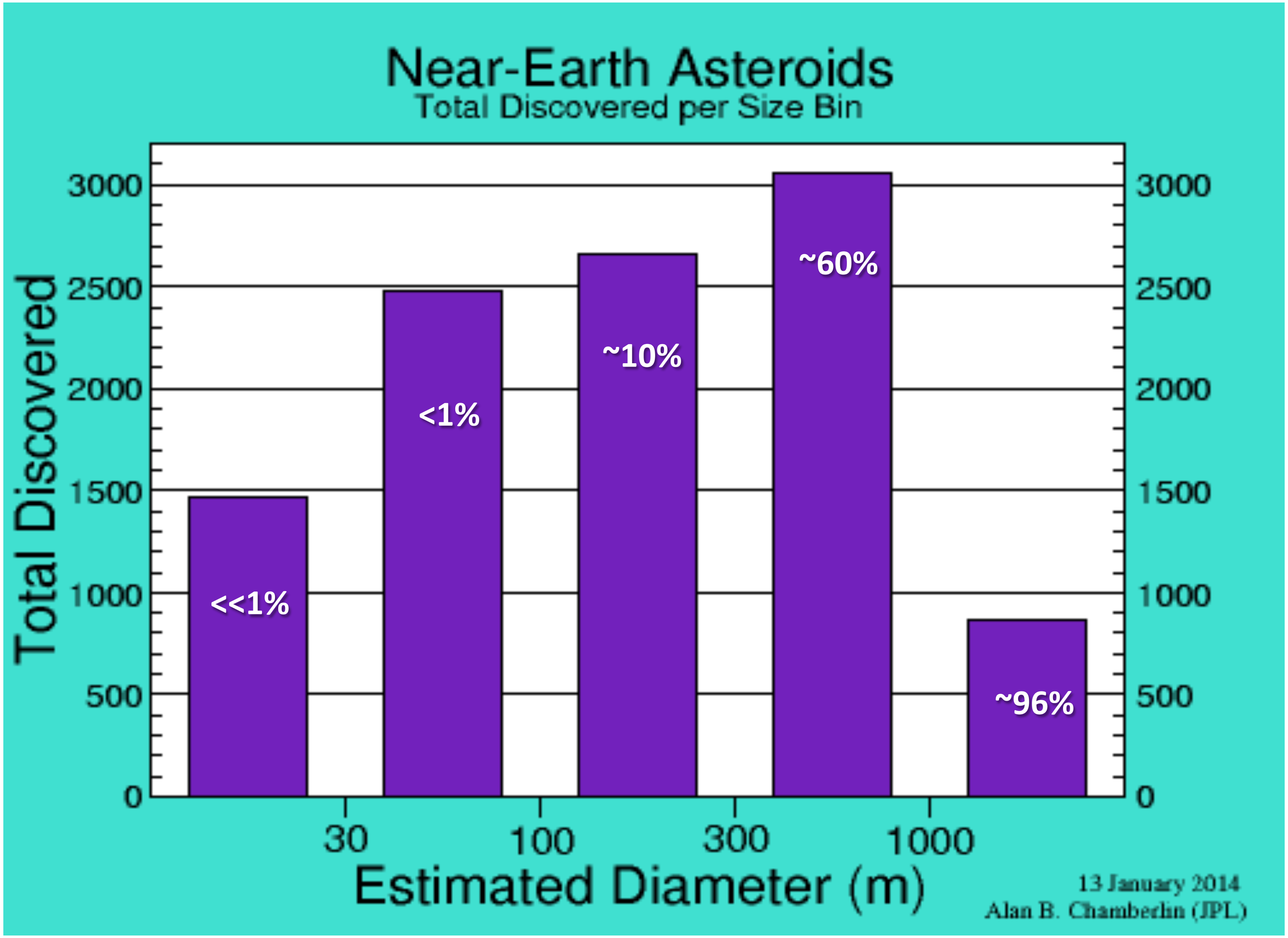
NEO Program Office @ JPL
- Program coordination
- Precision orbit determination
- Automated SENTRY

http://neo.jpl.nasa.gov/

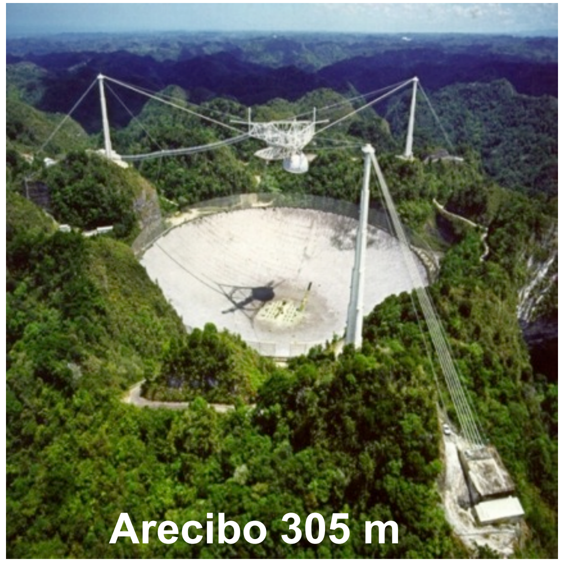


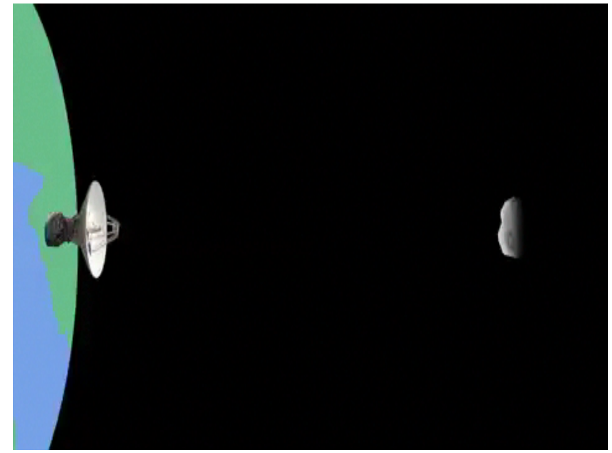


Known Near Earth Asteroid Population



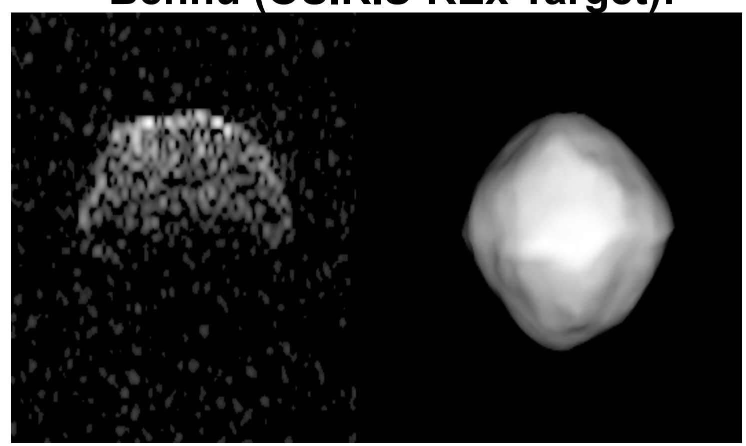
Radar Observations of NEOs





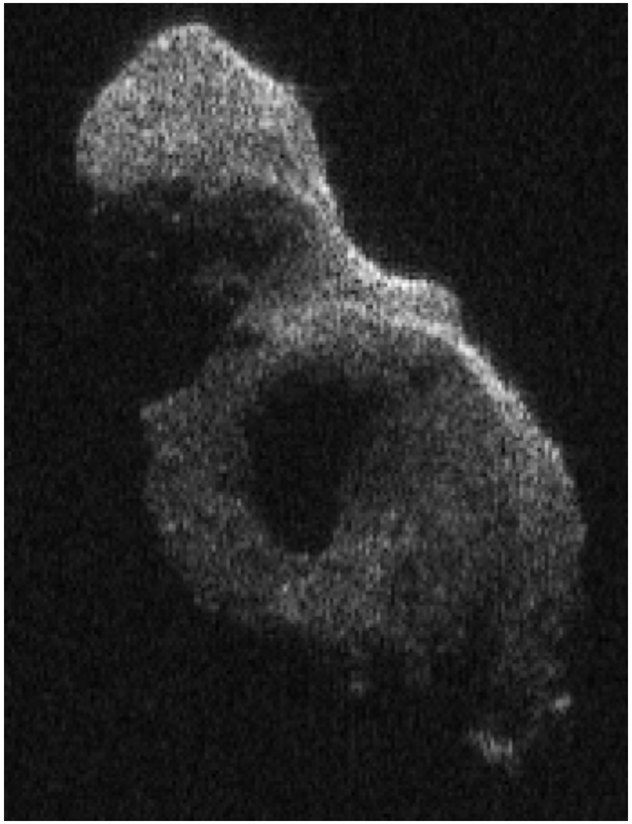
- These are complementary capabilities.
  - Arecibo has more power and range
  - Goldstone has more resolution and field of regard
- Currently, 70-80 NEOs are observed every year.
- Radar observations can provide:
  - Size and shape to within ~2 meters.
  - High precision range/Doppler orbit data.
  - Spin rate, surface density and roughness.

Bennu (OSIRIS-REx Target):

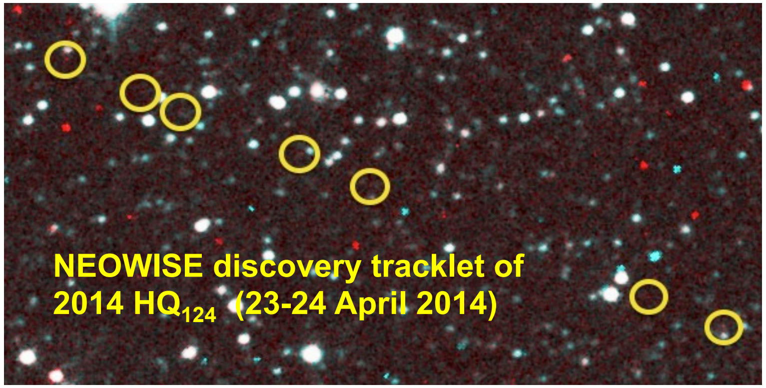


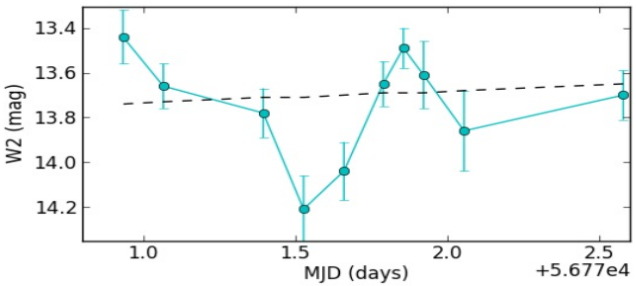
Observations **Shape Model**

Radar Imagery of NEA 2014 HQ_{124}



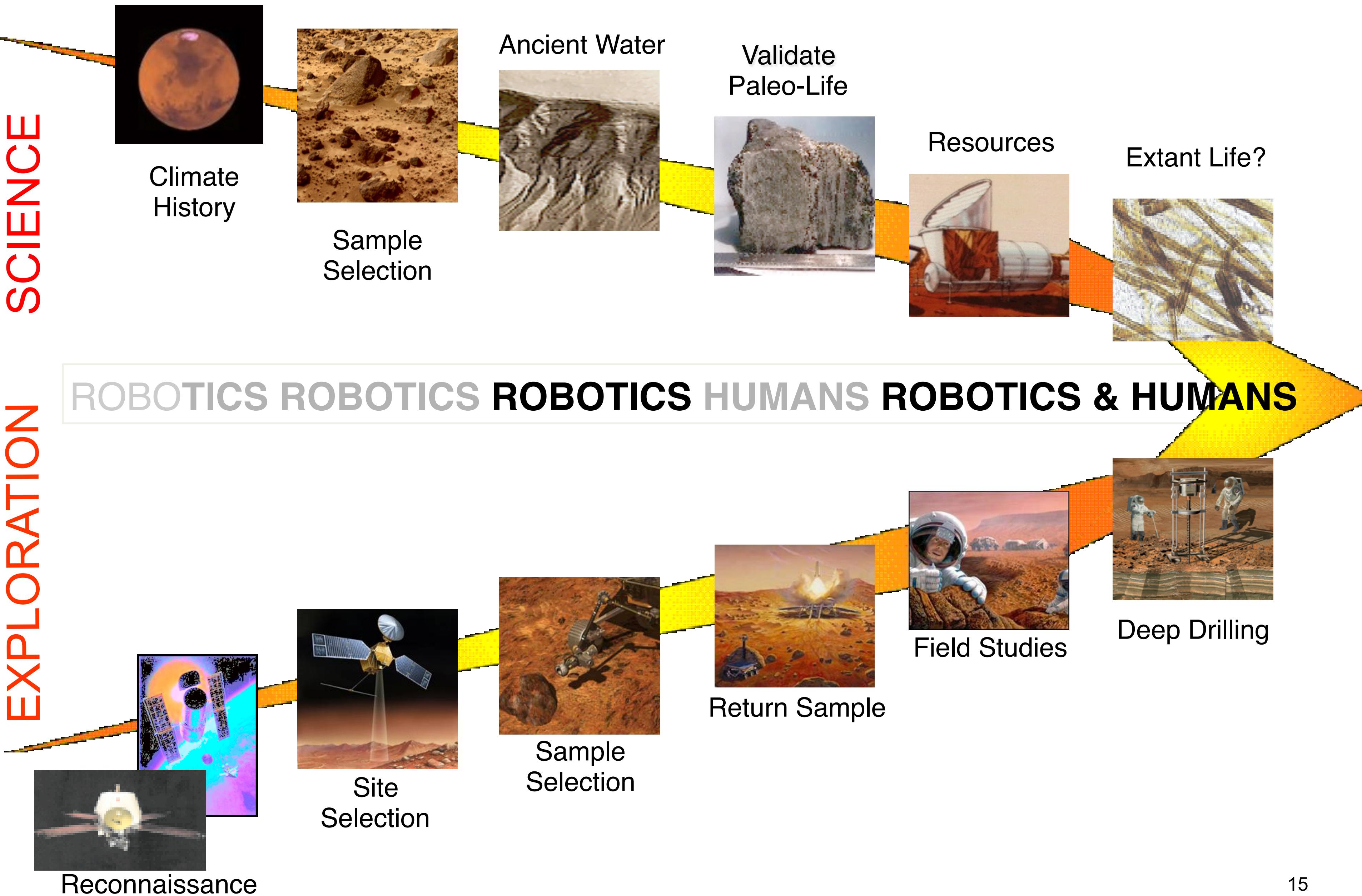
- Goldstone and Arecibo obtained bistatic radar images, of 2014 HQ_{124} on 8 June 2014, the day of its closest approach to Earth.
- Working together, with Goldstone emitting and Arecibo receiving, they produced spectacular imagery of this primitive body (left).
- Radar measurements indicate this NEA is ~370 meters along its long axis and appears to be a contact binary, where two objects migrate together until they form a single body.
- Large boulders appear to be imbedded into the main body.
- NEOWISE shows the NEA is elongated (with a 0.8 magnitude change in amplitude as the object rotates) and the measured rotation period of ~20 hours agrees with the radar data.



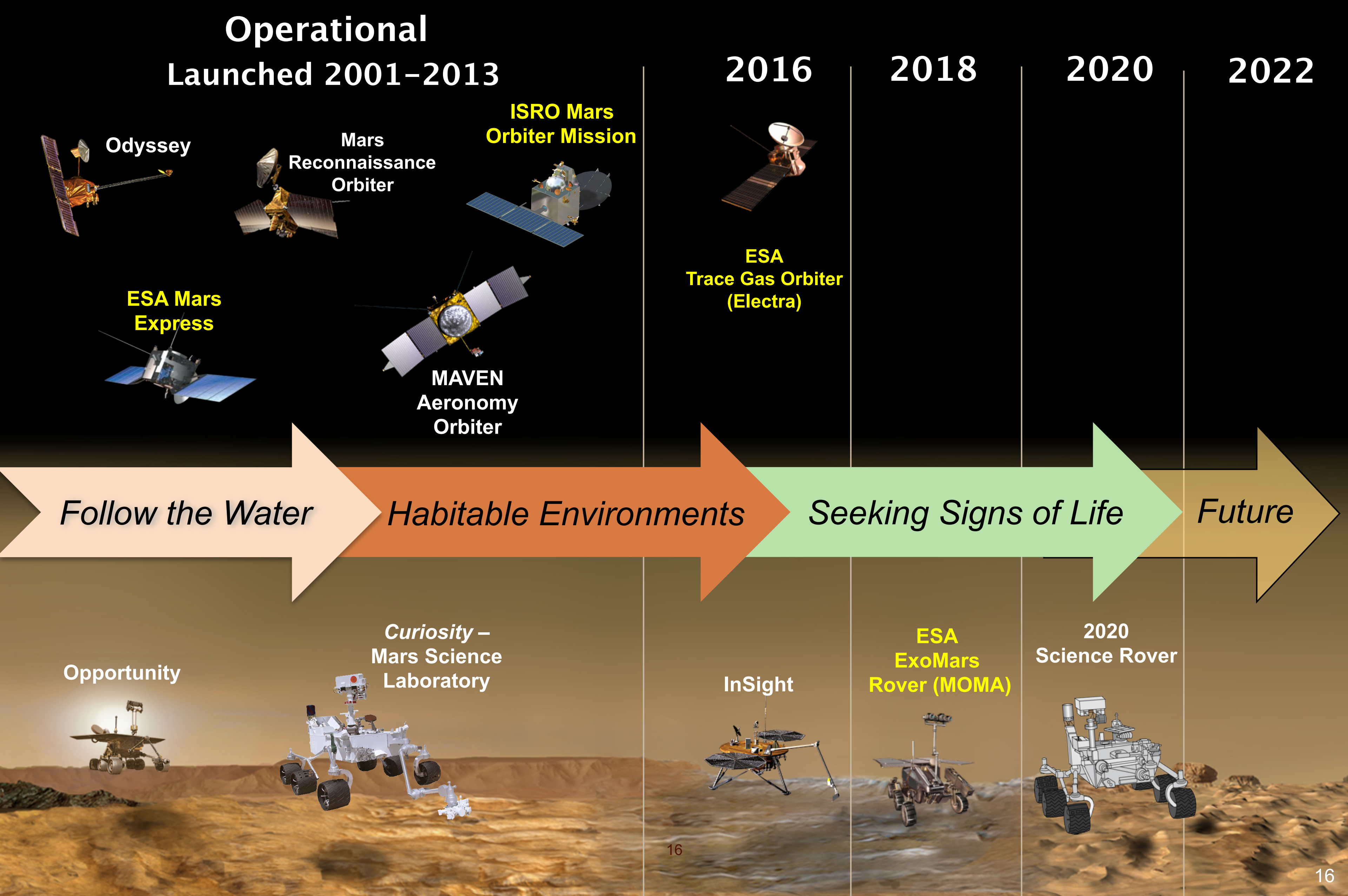


Joint Mars Missions

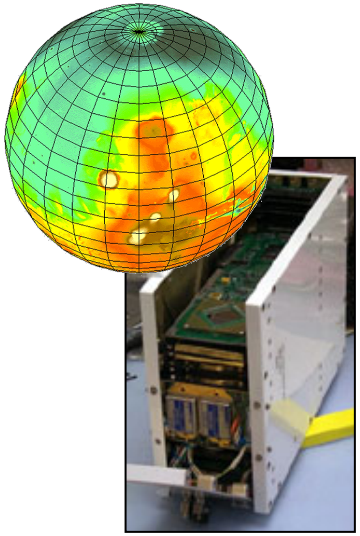
Interleaved Needs to Achieve “Humans at Mars”



Mars Missions this Decade

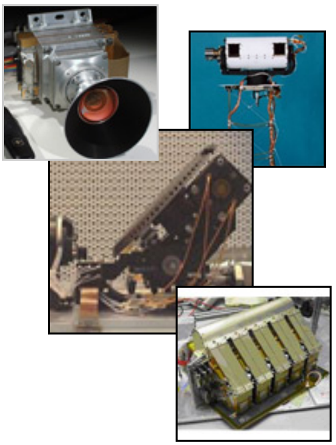


HEO and SMD Activities for Future Human Explorers

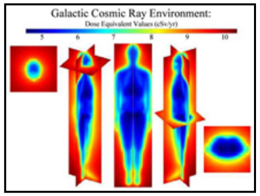


Mars Odyssey's Mars Radiation Environment Experiment (MARIE) collected data on the radiation environment (interplanetary cruise & Mars orbit) to help assess potential risks to future human explorers.

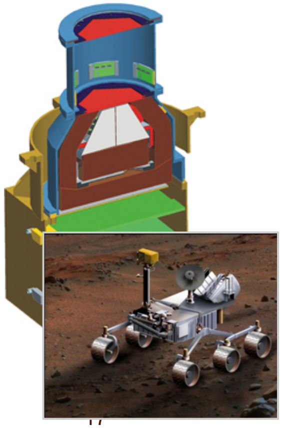
Phoenix's (MECA, TEGA, MARDI, SSI, RA/RAC) payload addresses all of the investigations in MEPAG Goal IV (Humans 2 Mars) except radiation measurements. Answering science questions and Strategic Knowledge Gaps.



Mars Science Laboratory's Radiation Assessment Detector (RAD) and Mars EDL Instrument (MEDLI) on its way to Mars now!

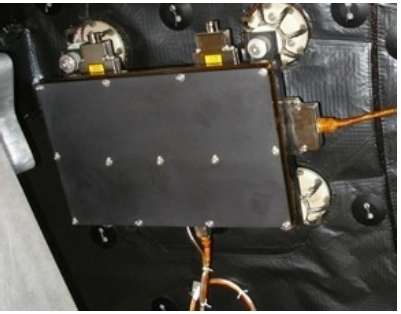


- RAD will characterize the radiation environment on Mars surface
  - Joint activity with SMD & HEOMD
  - RAD recently was able to measure how much radiation astronauts will be subjected to en-route to Mars
- MEDLI will measure the atmospheric conditions and performance of the MSL heatshield during entry and descent at Mars
  - Important information for the design of entry systems for future planetary missions.

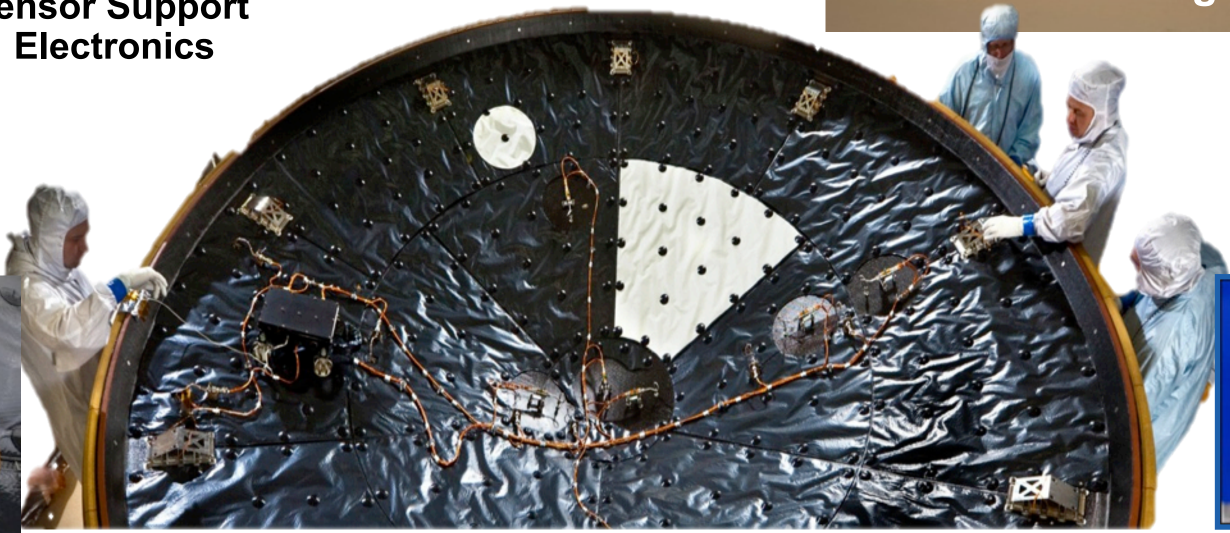


MEDLI: MSL Entry, Descent and Landing Instrumentation (2006-2012)

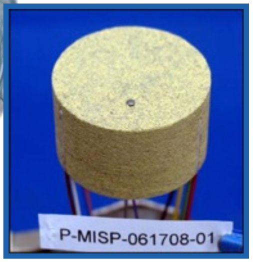
- MEDLI consisted of 7 heatshield pressure ports, 7 integrated sensor plugs, and support electronics
- Gathered engineering data during MSL's entry and descent for future Mars missions:
  - Aerothermal, aerodynamic, and thermal protection system performance
  - Atmospheric density and winds



Sensor Support Electronics



Mars Entry Atmospheric Data System (MEADS)



MEDLI Instrumented Sensor Plug (MISP)

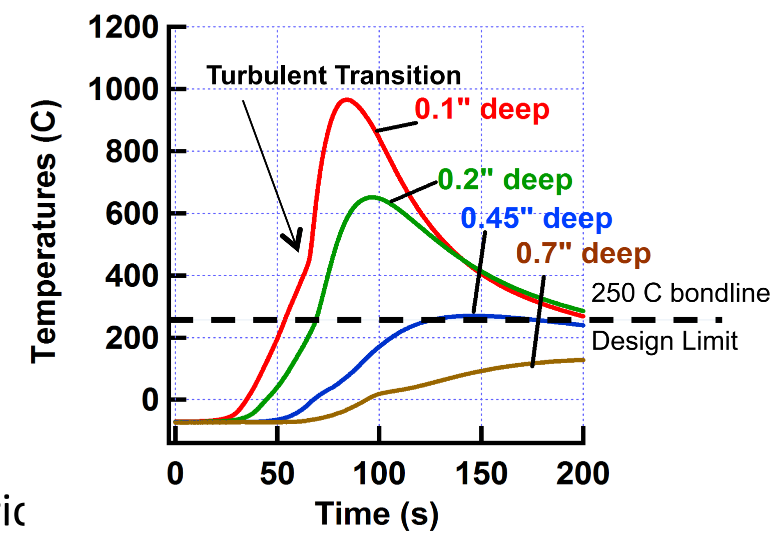
The MEDLI suite made MSL the first extensively instrumented heatshield ever sent to Mars

Partnership between HEOMD, ARMD, and SMD

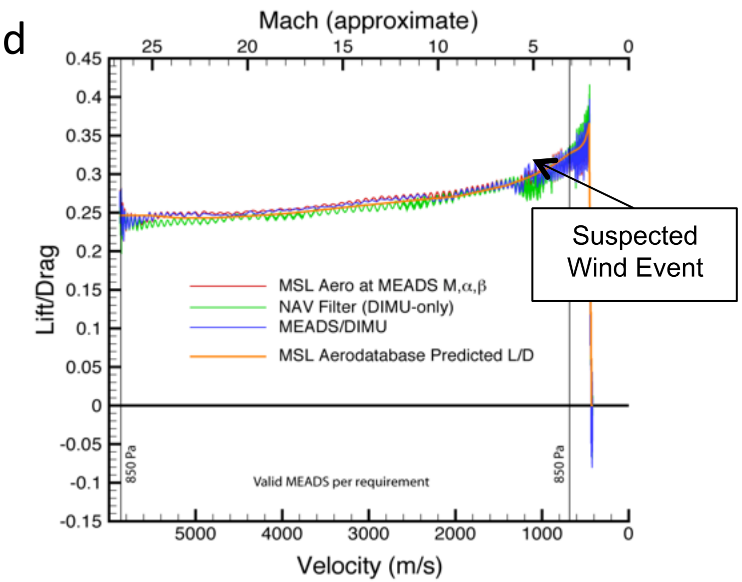
What We Learned From MSL MEDLI

- **Reduced required aerothermal environment and TPS design margins**
  - Potential 40%-50% reduction in forebody TPS thickness (~100 kg mass saving)
  - Eliminated unknown unknowns that could not be addressed by ground testing
  - Knowledge applied to InSight margin policy
- **Improved reconstruction of guided hypersonic entry**
  - Separated capsule aerodynamics from atmospheric contributions to deceleration
    - Independent pressure measurements provided a density profile to both engineers and scientists
  - Validated pre-flight predicted Aerodynamics
    - Measured trim angle agrees to within 0.5 deg
    - Measured drag agrees to within 1-2%
- **Demonstrated robust and reliable flight instrumentation for planetary EDL**

MSL MEDLI Flight Temperatures



MSL MEDLI L/D Reconstruction



Radiation Measurements on Mars

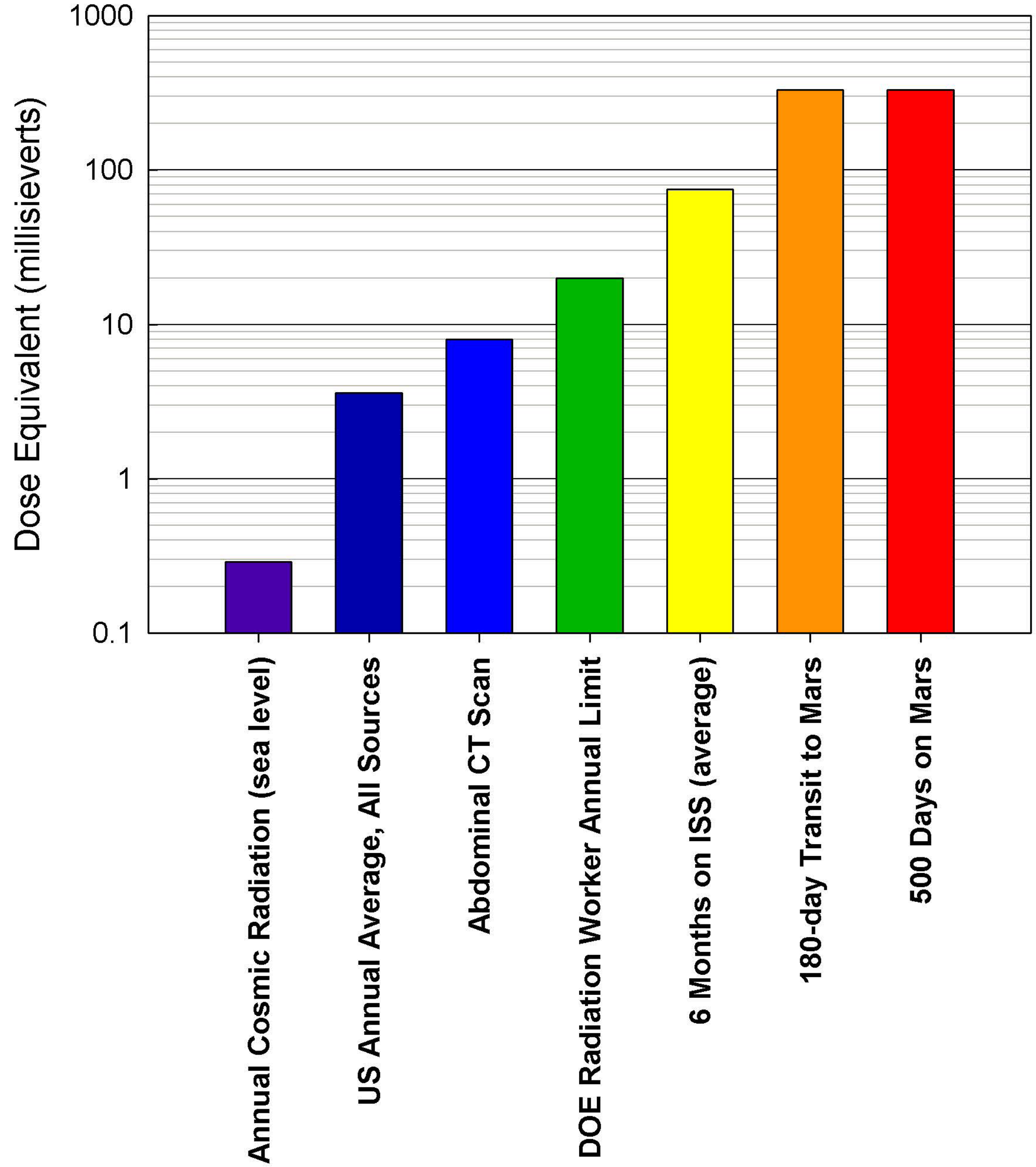
RAD measurements show:

A return trip to Mars results in an exposure of
Cruise: 662 +/- 108 mSv
On Mars: 320 +/- 50 mSv

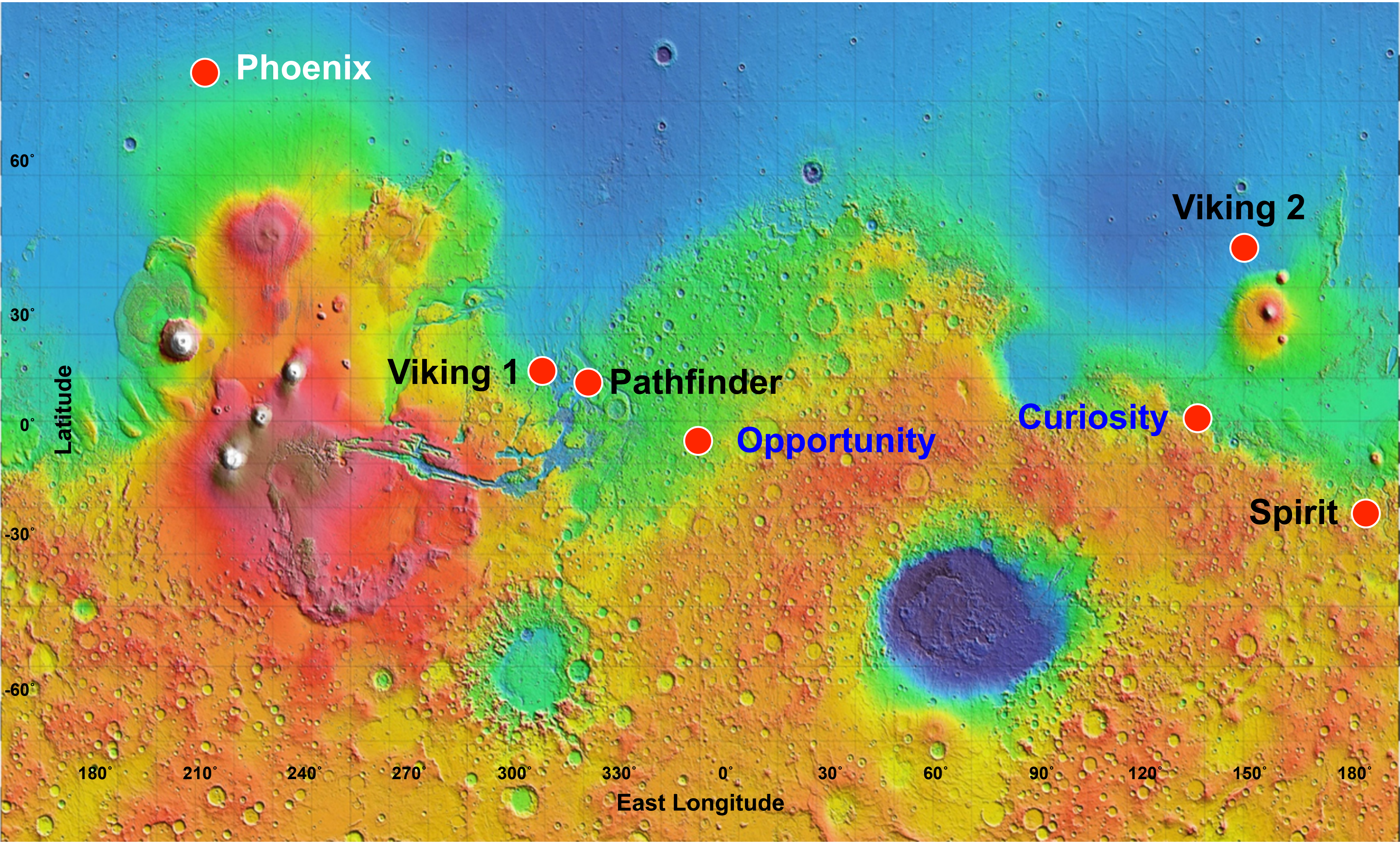
In total ~ 1000 mSv

Compare to:

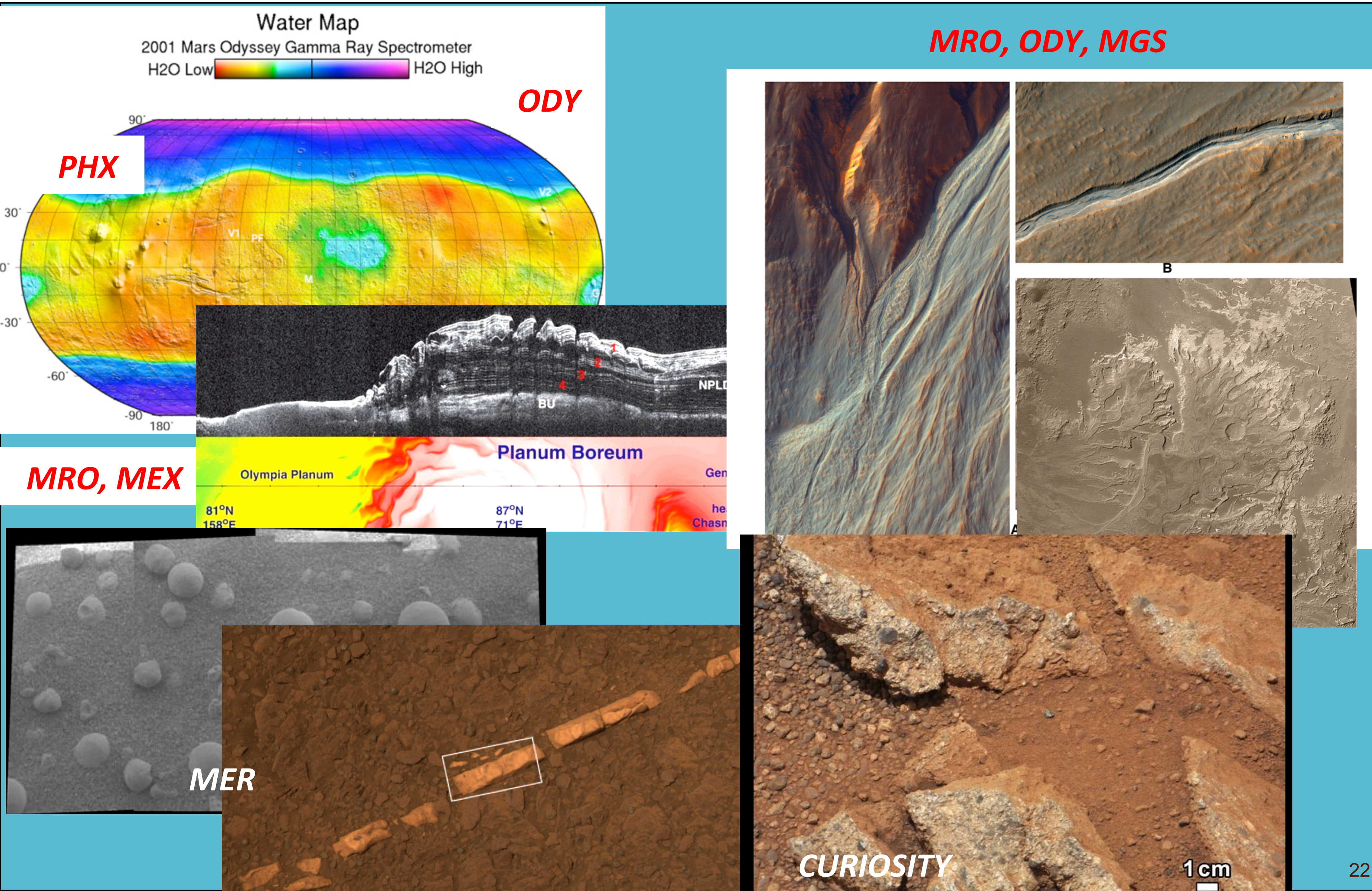
6 mos. on ISS: 75-90 mSv
Radiation worker: 20 mSv/y
Abdominal CT scan: 8 mSv



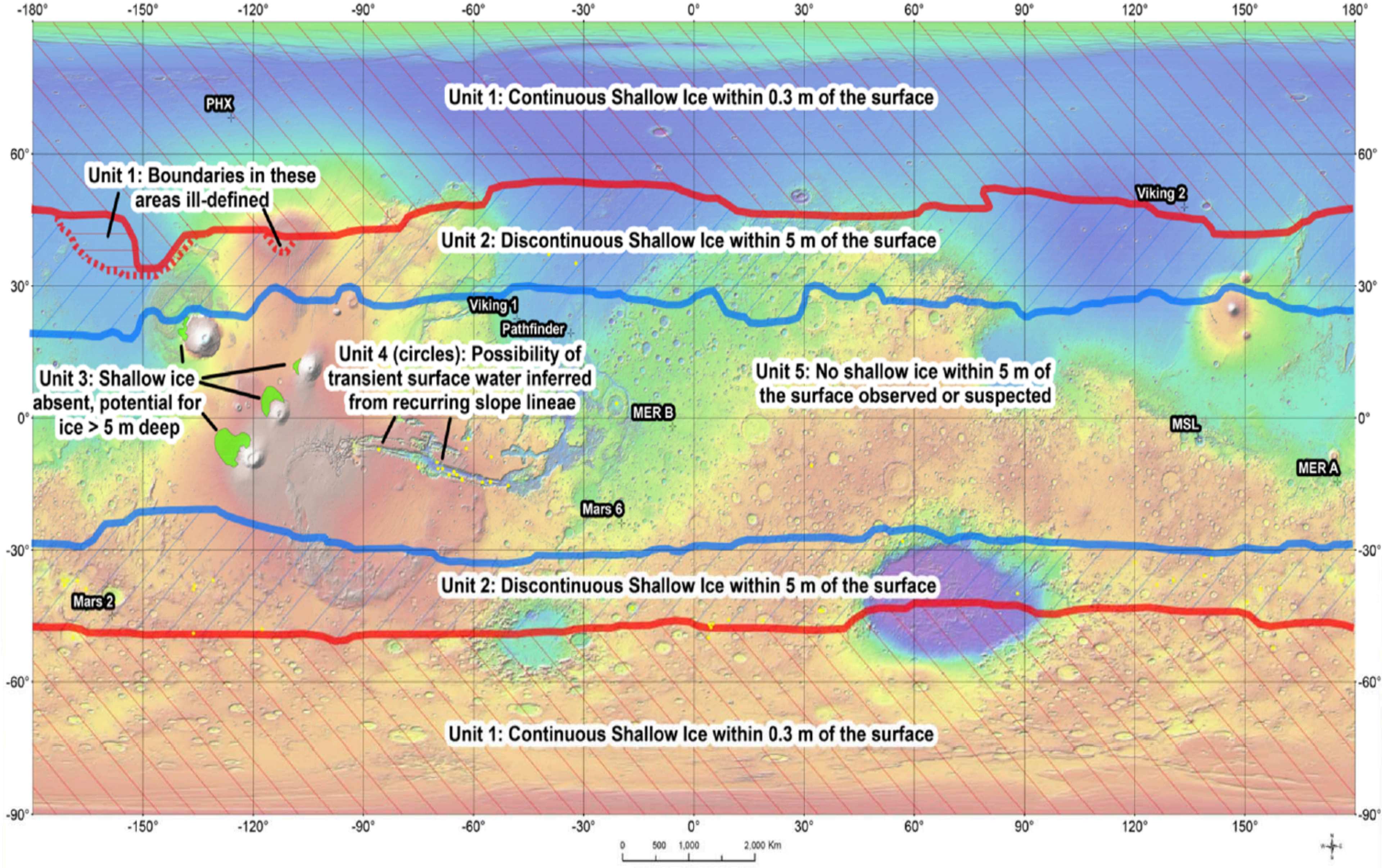
Location of the Landers and Rovers



Ground-Breaking Science Examples



Global Ground-Water Resources on Mars



Strategic Knowledge Gaps

- A Strategic Knowledge Gap (SKG) is an unknown or incomplete data set that contributes risk or cost to future human Mars missions
- SKGs are not unique to human exploration; all NASA missions are designed based upon what is It is known and what is not
- Science measurements are the greatest source of strategic Knowledge that has benefitted future human Mars exploration

For Human Exploration - What's Left to Know?

In the past 50 years, robotic missions have contributed data that reduces the risks of future human Mars exploration

TODAY

No data,
Most "unknowns"

Complete data sets
Planet completely characterized

There's more to know, but we're well on our way

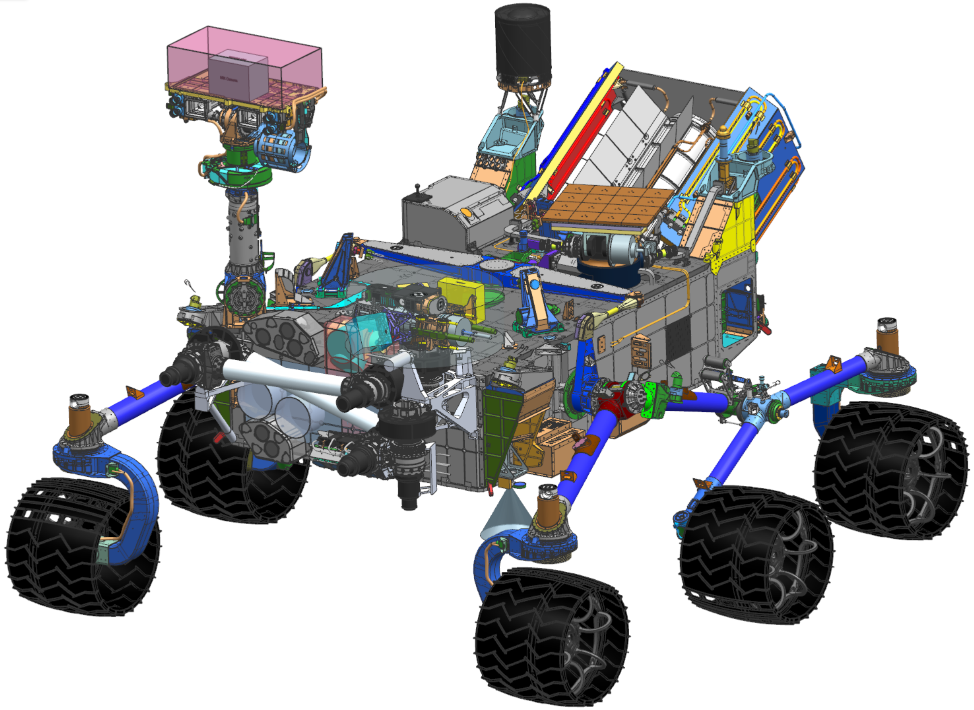
Mars 2020 Rover

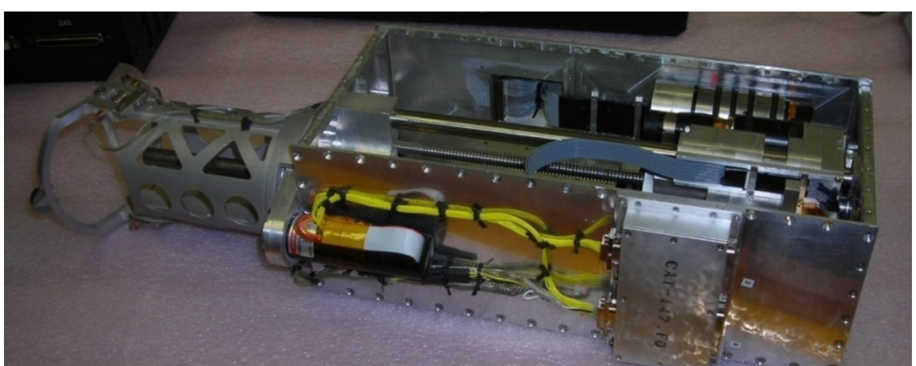
Seeking signs of life: Mars 2020 Rover

Conduct rigorous *in situ* science

Geologically diverse site of ancient habitability

Coordinated, nested context and fine-scale measurements





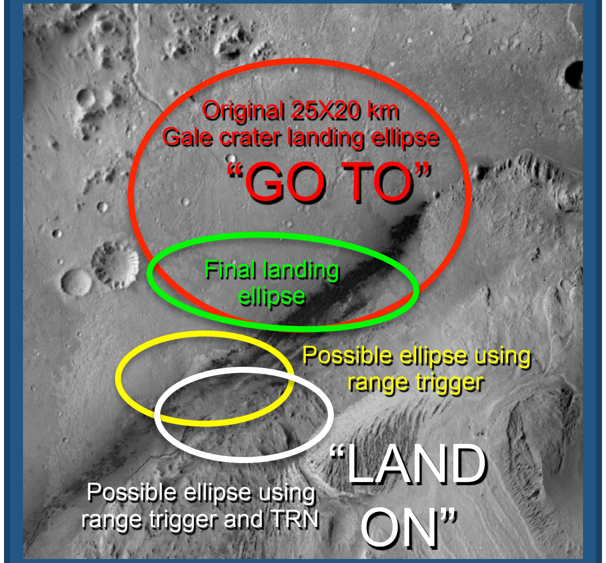
Enable the future

Critical ISRU and technology demonstrations required for future Mars exploration

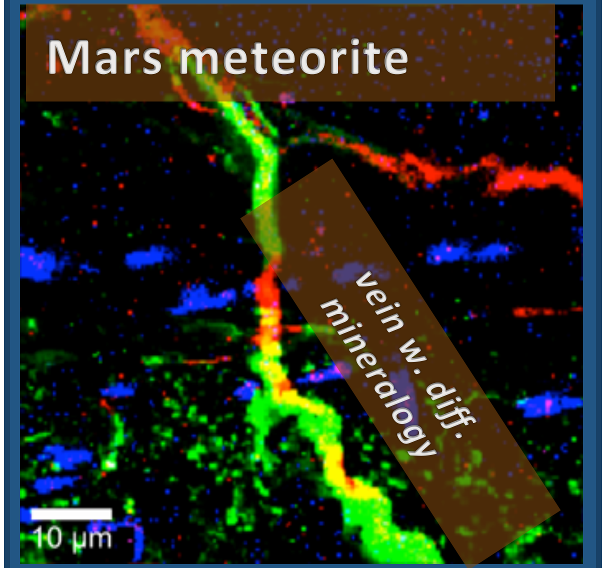
Returnable cache of samples

Why We're Excited About Mars 2020

The 2020 Mars Rover mission offers many important advances relative to MER and MSL:

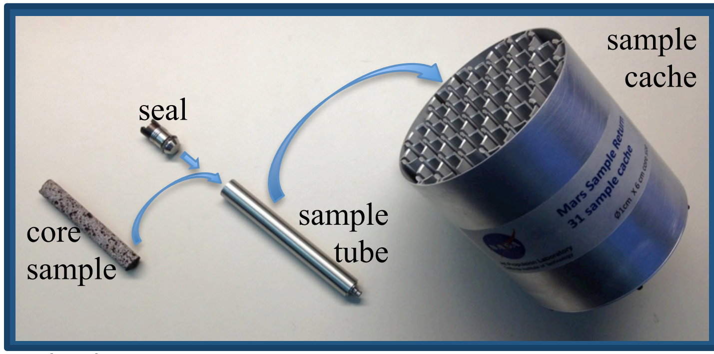


Potential to land on high priority scientific targets previously out of reach, shorten drive distances



Measurements of fine-scale mineralogy, chemistry, and texture in outcrop (petrology)

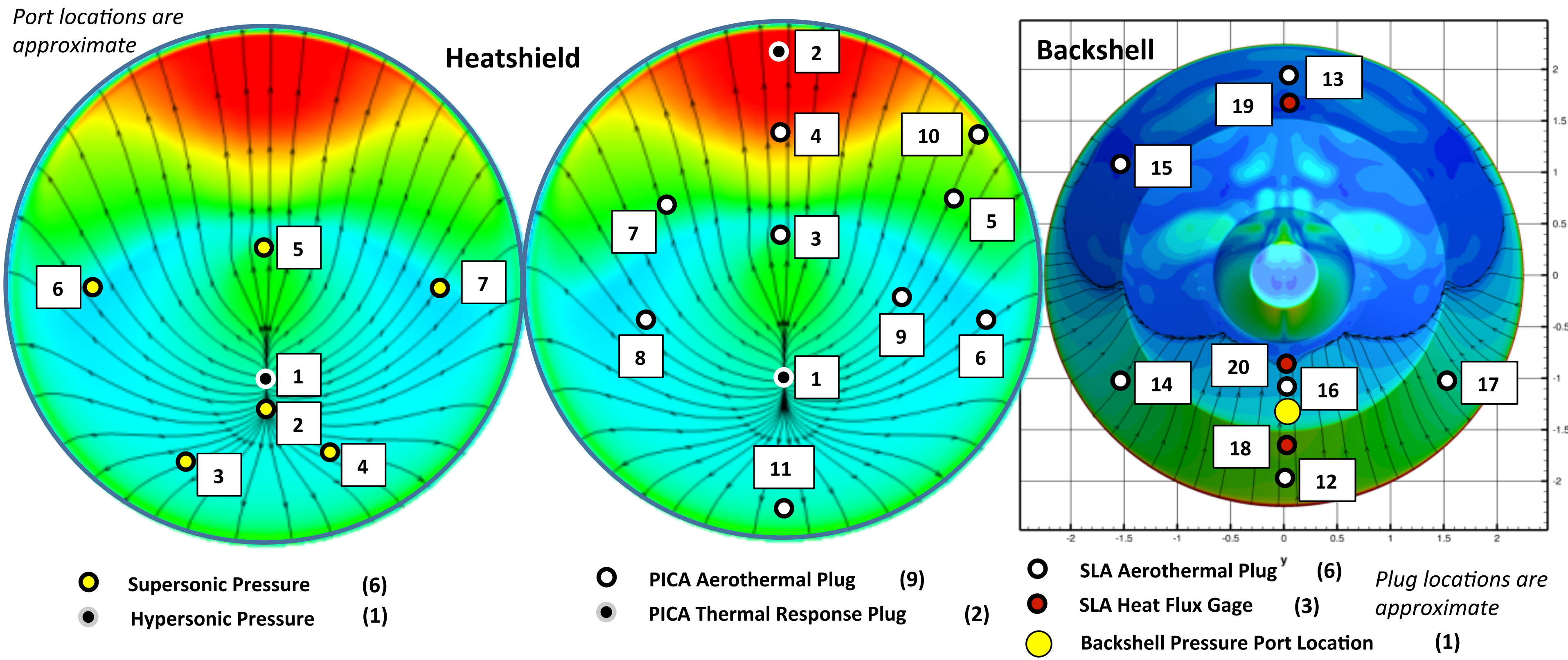
Payload designed to recognize potential biosignatures in outcrop



The ability to collect compelling samples for potential future return

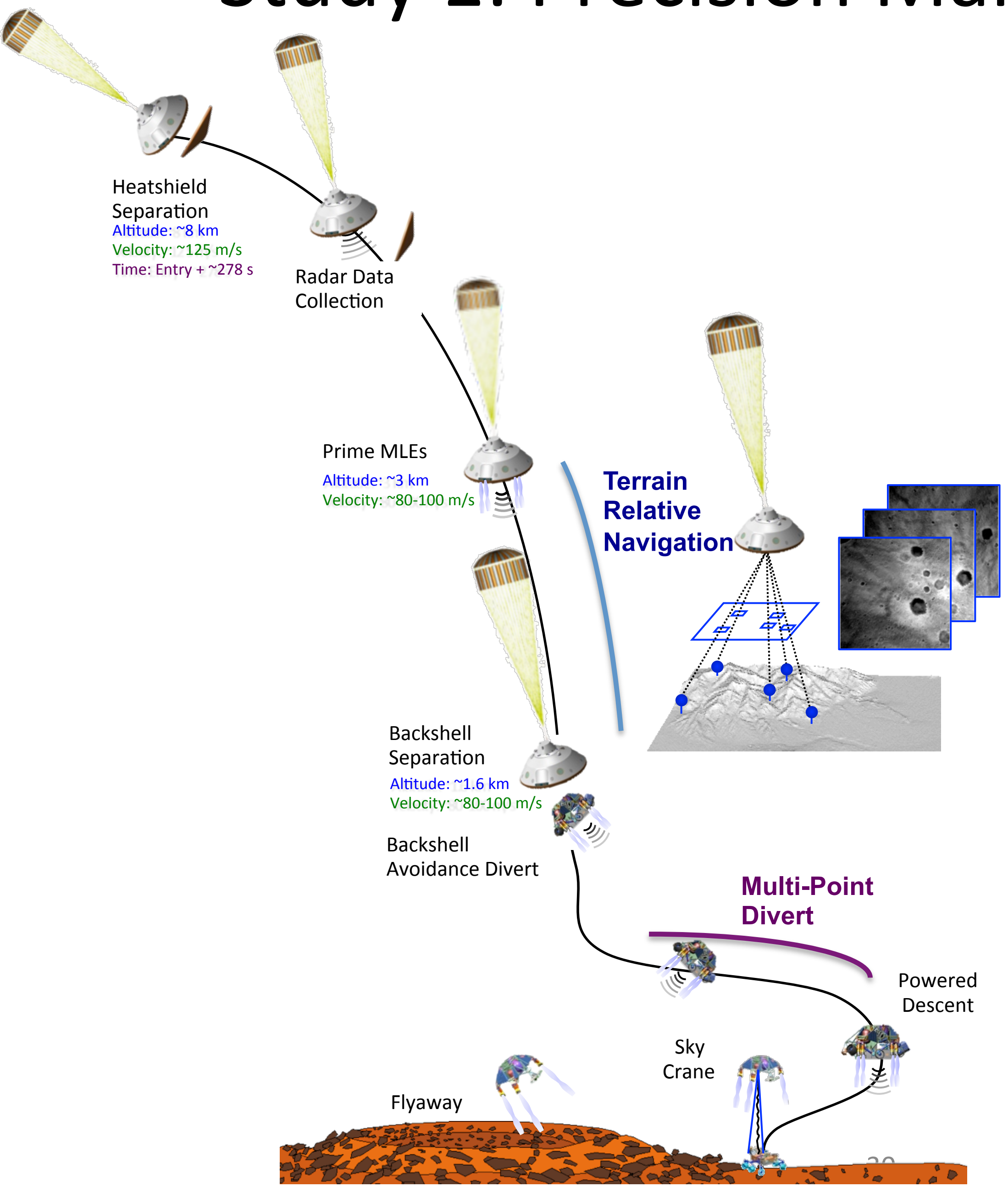
Prepare for the future human exploration of Mars

MEDLI2 for Mars 2020: Improved Knowledge



- **Improvements over MEDLI on MSL:**
  - Improved supersonic aerodynamics resolution **+ backshell measurement**
  - Improved near-surface thermal resolution
  - Improved spatial thermal resolution **+ backshell measurements**

Study 1: Precision Mars 2020 Landing



Terrain Relative Navigation

Works by taking images during parachute descent & matching them to an onboard map

- Uses a dedicated compute element, camera, & an inertial measurement unit
- Yields a position solution

Performs terrain relative navigation while the spacecraft is priming the descent engines

- Operating during priming imposes no altitude "cost"

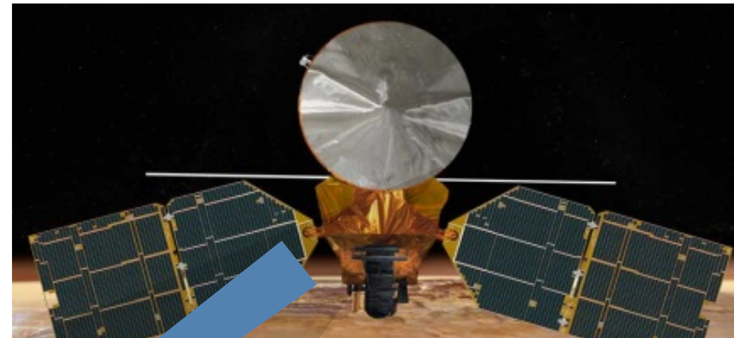
Multi-Point Divert

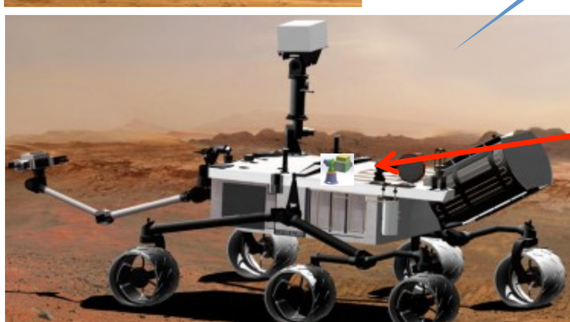
- Uses position solution and list of safe landing locations to select a landing target
- Augments original MSL backshell avoidance divert
- Uses original divert distance capability (no additional fuel or altitude needed)

Study 2: Optical Proximity and DTE Links Tech Demo

First ever optical proximity link at up to 50 Mb/s
- To lasercom-equipped orbiter
- Presumes commensurate rover and lasercom lifetime

First ever DTE planetary optical link at ≥40 kb/s (no orbiter required; can be done as soon a Plan allows)
- Uses Palomar 5 meter ground station w/STMD-funded photon counting detector
- Link characterization; Doppler measurement; Dust characterization;
- Optical comm ConOps practice
- Raw science data downlink (potential)





Beacon-assisted acquisition

For Proximity link:
- Wide-angle beacon on orbiter illuminates rover

For DTE:
- Laser beacon from Earth at near ranges
- Earth image serves as beacon at far ranges

Research & Analysis Activities

SSERVI Selected Teams

•**Bill Bottke**, Southwest Research Institute. *"Institute for the Science of Exploration Targets: Origin, Evolution and Discovery"*

•**Dan Britt**, University of Central Florida. *"Center for Lunar and Asteroid Surface Science"*

•**Ben Bussey**, Applied Physics Lab, Johns Hopkins University. *"Volatiles, Regolith and Thermal Investigations Consortium For Exploration and Science (VORTICES)"*

•**Bill Farrell**, Goddard Space Flight Center. *"Dynamic Response of Environments at Asteroids, the Moon, and moons of Mars (DREAM2)"*

•**Tim Glotch**, Stony Brook University. *"Remote, In Situ and Synchrotron Studies for Science and Exploration"*

•**Jennifer Heldmann**, Ames Research Center, *"Field Investigations to Enable Solar System Science & Exploration"*

•**Mihaly Horanyi**, University of Colorado. *"Institute for Modeling Plasma, Atmospheres and Cosmic Dust (IMPACT)"*

•**David Kring**, Lunar and Planetary Institute. *"Inner Solar System Impact Processes"*

•**Carle Pieters**, Brown University. *"Evolution and Environment of Exploration Destinations: Science and Engineering Synergism (SEEED)"*

SSERVI Recommended Institute - Programmatic Balance

Role of Target Body(s) in revealing the origin and evolution of the inner Solar System	Pieters, Bottke, Kring, Horanyi
Target Body structure and composition	Heldmann, Britt, Pieters, Bussey, Bottke, Kring, Glotch
Innovative observations that will advance our understanding of the fundamental physical laws, composition, and origins of the Universe	Farrell, Horanyi
Moon, NEA, and Martian moon investigations as windows into planetary differentiation processes	Heldmann, Pieters, Bussey, Bottke, Kring, Glotch
Dust and plasma interactions on Target Body(s)	Britt, Farrell, Horanyi
Near-Earth asteroid characterization (including NEAs that are potential human destinations)	Britt, Farrell, Pieters, Bussey, Bottke, Kring, Horanyi, Glotch
Geotechnical properties (Moon, NEAs, Mars)	Heldmann, Britt, Pieters, Bussey, Kring, Horanyi, Glotch
Regolith of Target Bodies	Heldmann, Britt, Farrell, Pieters, Bussey, Kring, Horanyi, Glotch
Radiation	Farrell, Horanyi, Glotch
Volatiles (in its broad sense) and other potential resources on Target Body(s)	Heldmann, Farrell, Pieters, Bussey, Glotch
In-Situ Resource Utilization (ISRU)/ Prospecting (Moon, NEAs, Mars)	Heldmann, Bussey, Glotch
Propulsion-induced ejecta (Moon, NEAs, Mars)	Britt
Operations/Operability (all destinations, including transit)	Heldmann, Kring, Glotch
Human health and performance (all destinations, including transit)	Glotch

Science emphasis

Exploration emphasis (SKGs)

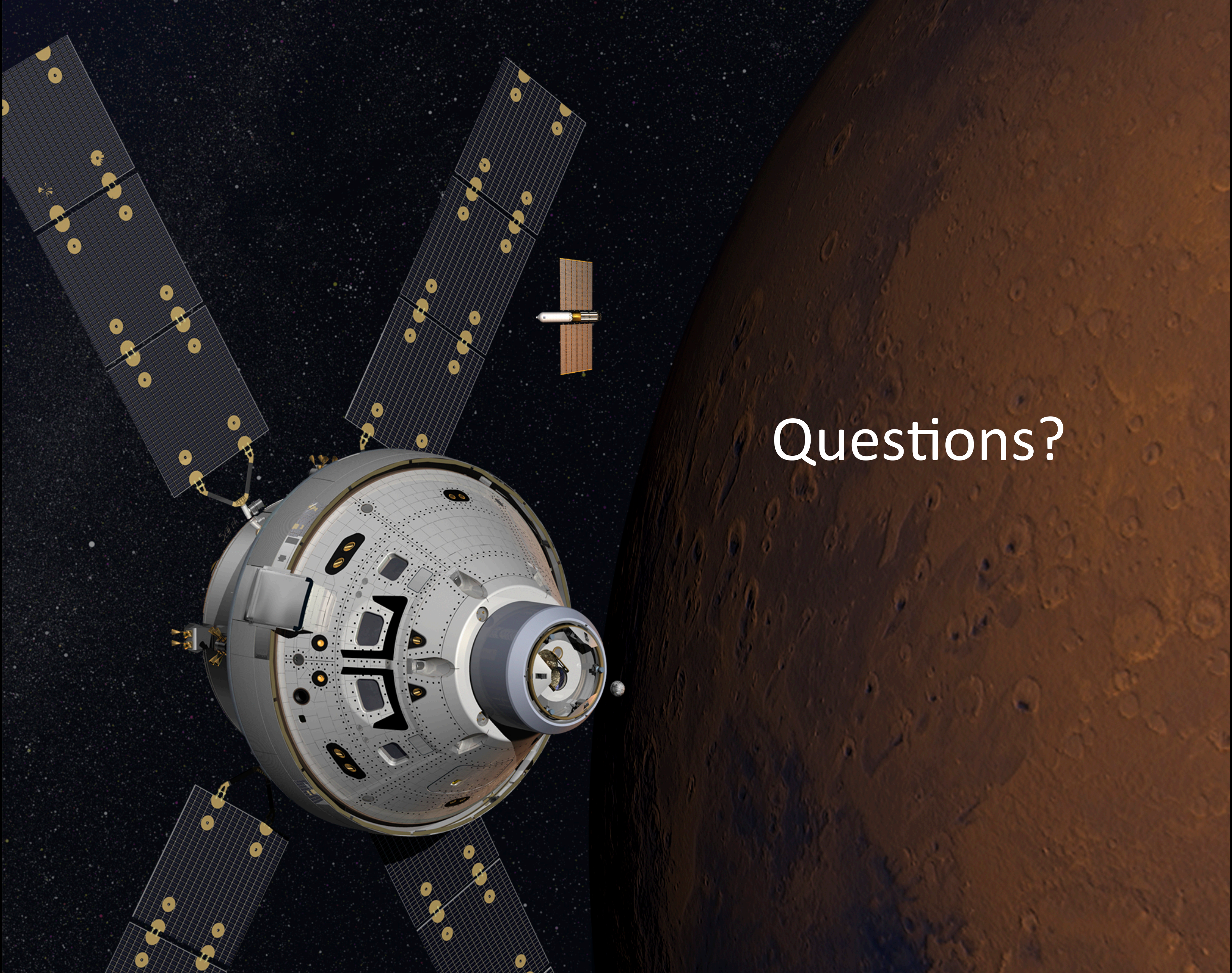
Future Activities

Future Joint Activities

- Technologies: EDL, Atomic Clock, Ion Engines…

- Mars Missions in the next decade: TBD
  - Optical Com from the Mars to Earth & back
  - High resolution imaging (replace MRO-Hirise)
  - Joint rover or platform: seismic, weather, SAR, ISRU/SKGs ..

- Space Launch System (SLS)


Questions?